Experiment 6
Chemical Formula Detective

Background

Different elements can form chemical bonds to create compounds. For example, sodium and chlorine combine to form sodium chloride, NaCl. In the chemical formula NaCl, there is a 1:1 ratio of sodium ions:chloride ions. However, not all compounds form in a 1:1 ratio of their constituent elements. If they did, John Dalton would have been correct in 1803 when he proposed the chemical formula of water as HO*. Of course, we now know that the correct chemical formula of water is H_2O, in which there is a 2:1 ratio of hydrogen atoms to oxygen atoms. Since a mole is Avogadro's number of atoms, H_2O is also a 2:1 ratio of moles of hydrogen to moles of oxygen. Thus, the atom ratio is equivalent to the ***mole*** ratio (not a mass ratio) in a given chemical formula.

Chemistry students should appreciate the ability to predict chemical formulas based on nomenclature rules. For hundreds of years, the chemical composition of many compounds has been studied, and the results generalized into the nomenclature rules used today. These rules allow the accurate prediction of chemical formulas for many ionic compounds without doing any experimentation. For example, the nomenclature rules can be used to correctly predict the formula of magnesium iodide as MgI_2 rather than MgI. The curious student of chemistry will wonder how such a prediction could be verified by experimental means.

Your task is to determine the chemical formula of an unknown copper chloride hydrate by experiment. An ionic hydrate is an ionic compound that has water molecules trapped within its crystal lattice (See your textbook, Section 3.8, for more information). For example, Epsom salt (**$MgSO_4 \cdot 7H_2O$**) is a heptahydrate of magnesium sulfate: within one mole of magnesium sulfate heptahydrate are seven moles of water. This water can be driven off by heat to form the anhydrous (dehydrated) ionic compound, magnesium sulfate.

Thus, the chemical formula of your unknown copper chloride hydrate will be in the general form **$Cu_xCl_y \cdot zH_2O$**. Your objective is to determine what the actual formula is (what are the integers *x*, *y*, and *z*?) You will be required to make careful mass measurements and to figure out what information will need to be recorded and what calculations will be performed.

Good luck!

* John Dalton (1766-1844) made an assumption that when only one compound was formed from two elements, they did so in the simplest ratio, 1:1. (Water was the only known compound formed from hydrogen and oxygen at the time. Hydrogen peroxide, H_2O_2, was not discovered until 1815.) Since the mass ratio of oxygen to hydrogen in water is 8:1, he assigned the mass of hydrogen (the lightest element) to be 1 and , assuming the formula HO, assigned the value 8 to oxygen. The correct formula of water and the relative atomic mass of oxygen as 16 was a puzzle that would not be solved for another fifty years, despite evidence on the combining volumes of hydrogen and oxygen gas in a 2:1 ratio. Avodgadro's hypothesis would later be used to interpret this evidence correctly.

The Overall Strategy

The formula will be determined by careful mass measurements. Remember, you are starting with $Cu_xCl_y \cdot zH_2O$. You will decompose this into several components. The first step is to gently dehydrate a known mass of your sample. The resulting dehydrated sample will be weighed to determine the amount of water lost (which is the zH_2O part).

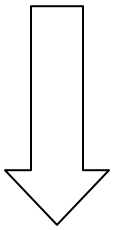
The dehydrated copper chloride (now just Cu_xCl_y) will be made into a solution, dissolving the sample into copper ions and chloride ions. The copper ions will be reduced* to copper metal, which will be collected, dried, and weighed.

The remaining task is to determine the mass of chloride** in the compound $Cu_xCl_y \cdot zH_2O$, which can easily be done by mass difference (the masses of the initial sample, water lost, and copper were determined in the previous steps).

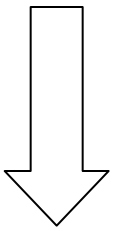
These steps should give you enough data to figure out the chemical formula of the unknown copper chloride hydrate.

A flow chart for today's experiment:

$Cu_xCl_y \cdot z\ H_2O$



Cu_xCl_y



Cu

* Reduction of copper means that copper ions gain electrons to form copper metal. These electrons will be provided by the oxidation (loss of electrons) of an aluminum wire in the solution.

** The mass of chloride is being determined. The difference between the mass of chlorine and chloride is negligible. (Why?)

Experiment 5 Turn-in Sheets

Chemical Formula Detective

Experimental Procedure

NOTE: **Keep and label everything**! Do not throw anything away until you are finished with the lab experiment and calculations!

ALSO: The procedure will not tell you what masses to record, so make sure you are paying attention and that your data chart is already created.

Use this space to record your observations and/or data

1. Weigh an empty, dry crucible and put about one gram of your unknown copper chloride hydrate into it, breaking up any clumps that are present. Record the precise mass of your sample using significant figures.

2. Place the uncovered crucible on a clay triangle supported by an iron ring clamp. Holding the Bunsen burner in your hand, move it back and forth under the crucible to **GENTLY** heat the sample. **Do not overheat it**. The hydrated crystals change color and will look like tobacco when dehydrated (but should not be allowed to turn black). Record the color change. Continue heating for two minutes after all the crystals turn color. Cover and cool the crystals for 15 minutes.

Safety
The crucible will be very hot. Handle it only with tongs or oven mitts.

Check to see if any green crystals remain after this time by gently rolling the crystals around the crucible (do not touch the crystals or use anything to stir them!). Repeat heating if green crystals remain.

At the end of this step, what data should be recorded?

Confirm with your instructor before proceeding!!!!!

3. Transfer the dehydrated sample to an empty 50-mL beaker. To ensure all the crystals have been transferred from the crucible to the beaker, use two 5 mL portions of distilled water to rinse the crucible contents into the beaker. Swirl the beaker to dissolve the crystals. The solution will turn color, signifying the presence of hydrated copper ions. Record the color change.

Use this space to record your observations and/or data

4. Obtain a piece of aluminum wire approx. 20 cm long. Wind it into a loose coil. Completely submerge it into the 50-mL beaker containing your copper solution. Record what you observe.

5. The reaction will slow down as the surface of aluminum is reduced. Use a glass stirring rod to scrape the copper from the wire as completely as possible, exposing more of the surface for reaction.

What changes do you observe as the reaction slows down? How will you know when it is over? Record your observations. With your partner, determine when the reaction is finished.

Safety
HCl is corrosive. In case of contact with skin, rinse with plenty of water and notify your instructor. Wear goggles at all times in the chemistry laboratory.

6. After the reaction is finished, add 5 drops of 6M HCl to dissolve any insoluble aluminum salts and clear up the solution.

7. In the next steps, you will be collecting the copper by filtration. You will use a funnel and 1-2 pieces of filter paper.

Before proceeding, discuss with your lab partner the best method for determining the mass of copper collected on the filter paper. (Remember, it will be difficult to scrape the copper off the filter paper without losing some of it).

Discuss your idea with your lab instructor. The filtration setup is discussed in the next step.

8. Set up a small Büchner funnel fitted with a moistened piece of filter paper (sketch the setup in the right-hand column with labels) and attach it to the water aspirator. With light suction, transfer all of the copper to the funnel. Use distilled water as necessary for the transfer and also to rinse the copper. Turn off the suction and add 10mL of 95% ethanol to the funnel. After a minute, turn on the suction again and leave it on for 5 minutes.

Make a detailed sketch of your setup here for future reference.

9. The remaining copper is best collected on a watch glass, with or without the filter paper. Dry it under a heat lamp about 5-10 minutes.

Do not clean up until your calculations are finished or until instructed to do so.

Waste Disposal

The liquid waste and copper produced in the experiment should be put into the appropriately labeled waste containers in the hood. Never pour chemical waste into the sink unless directed by your instructor.

Data

Take your collected data and organize it into a data table in a logical fashion. Always use permanent ink for data.

Calculations

Show your work. It is crucial that you use the proper number of significant figures.

1) Determine the number of moles of water lost from the hydrated unknown.

2) Determine the number of moles of copper collected.

3) Determine the number of moles of chloride there must have been in the compound.

4) What is the mole ratio of copper to chloride (set copper equal to 1)? 1 : ___

5) What is the mole ratio of copper to water lost (set copper equal to 1)? 1 : ___

6) Use the answers from 4 and 5 above to determine the chemical formula of the copper chloride hydrate. Also provide the chemical name of this hydrate. (Note: It is possible that your chemical formula may look strange due to experimental error.)

Follow-Up Questions

1) Ask your instructor for the correct formula of the unknown hydrate: _____

How'd you do?

2) List at least two sources of error in this experiment that could have affected your results, whether or not you obtained the correct formula.[1]

3) What ions are present in the correct copper chloride hydrate? Give the sign and magnitude of their charges.

4) What color do you associate with the hydrated copper ion in the hydrate (what color are the crystals)? What happens to the color when the copper ions become dehydrated?

5) What effect would each of the following situations have on the calculation of the # of moles of copper in this experiment? Give a very brief explanation for each choice.

a) You removed the aluminum wire while the mixture was still blue or contained bubbles.

Continued on the next page

[1] Your instructor will assume that "random or human error" or "miscalculation" as sources of error were minimized, so do not state these. Instead, think about inherent flaws or incorrect assumptions in this particular experiment that lead directly to experimental errors in measurement.

b) You added twice as much aluminum wire as necessary to the copper chloride.

c) You couldn't scrape all the copper off the aluminum wire.

d) The dehydration was not complete because your crystals were still green. You did not reheat to complete the dehydration.

Pre-Lab Assignment

Refer to Chapter 6 for preparation:

1. In your own words, what is the purpose of this experiment?

2. Read the procedure. Based on the flow chart, list all masses that are absolutely critical in obtaining during this experiment.

3. Epsom salt is $MgSO_4 \cdot 7\ H_2O$. What does the chemical formula become when this hydrate is gently heated? _____

4. A 1.00-g sample of an unknown hydrate of cobalt chloride is gently dehydrated. The resulting mass is 0.546g. The cobalt is isolated and weighs 0.248g. What is the formula of the hydrate? **Make sure you use an adequate number of significant figures, or your answer could be incorrect.**

a) Determine the number of moles of water lost from the hydrated unknown. _____

b) Determine the number of moles of cobalt collected. _____

c) Determine the number of moles of chloride in the compound. _____

d) What is the mole ratio of cobalt to chloride (set cobalt equal to 1)? 1 : ___

e) What is the mole ratio of cobalt to water lost (set cobalt equal to 1)? 1 : ___

f) Use the answers from parts d and e to determine the chemical formula of the cobalt chloride hydrate. It will have the form $\mathbf{Co_xCl_y \cdot z\ H_2O}$, where x, y, and z are integers that you determined from parts a through e.

formula of the unknown cobalt chloride hydrate: _____

5. In this experiment, you will determine the formula of a copper chloride. Copper usually exists as +1 and +2 oxidation states. **Give at least two possible chemical formulas** you expect for Cu_xCl_y, where x and y are integers